

INCLUSIVE DIRECT-PHOTON AND π^0 PRODUCTION IN PROTON-NUCLEON COLLISIONS

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We present a study of inclusive direct- γ and π^0 production in hadronic interactions that focuses on a comparison of the ratio of γ and π^0 yields with expectations from next-to-leading order perturbative QCD (NLO pQCD).

1 Introduction and the γ/π^0 Ratio

Direct-photon production in hadronic collisions at high transverse momenta (p_T) has long been viewed as an ideal vehicle for extracting the gluon content, $G(x)$, of hadrons. The sensitivity to $G(x)$ arises from the contribution of the Compton subprocess $gq \rightarrow \gamma q$ to direct- γ production. $G(x)$ is well constrained by other data for $x < 0.25$, but not at larger x . In principle, a precise measurement of direct-photon production at fixed-target energies can constrain $G(x)$ at large x , and such data have been used in fits to global parton distribution functions (PDF).

Deviations have been noted between measured inclusive direct-photon cross sections and NLO pQCD. Ratios of data to theory for both γ and pion production indicate substantial disagreement between data and pQCD, as well as between different experiments.¹ The latter is not completely surprising, because, especially for direct-photon production, signals are often small and backgrounds large, especially at lower energies. Several experiments show better agreement with NLO pQCD than others, but the results do not provide confidence in the theory nor in the quality of all data. Although it has been suggested that deviations from theory for both γ and pion production can be ascribed to higher-order effects of initial-state soft-gluon radiation, it seems unlikely that theoretical developments alone will accommodate the observed level of scatter in data/theory. These discrepancies mo-

tivated us to consider measurements of the γ/π^0 ratio over the available range of center-of-mass energies (\sqrt{s}). Both experimental and theoretical uncertainties tend to cancel in such a ratio, and it is also less sensitive to the treatment of gluon radiation. A sample of the ratio of direct- γ to π^0 cross sections for both data and NLO pQCD is given for incident protons, as a function of $x_T = 2p_T/\sqrt{s}$, in Figs. 1–3. The results at $\sqrt{s} = 19.4$ GeV are displayed in Fig. 1. For all measurements, theory is high compared to data. (The NLO calculations use a single scale of $\mu = p_T/2$, CTEQ4M PDFs,² and BKK fragmentation functions³ for pions.) Figure 2 shows the γ to π^0 ratio at $\sqrt{s} \approx 23 - 24$ GeV. Just as in Fig. 1, theory is high relative to data. At larger \sqrt{s} , the NLO value for the ratio agrees better with experiment, as seen in Fig. 3 for $\sqrt{s} = 31 - 39$ GeV. At even higher \sqrt{s} , theory lies slightly below the data.¹ A compilation of these results, displayed for simplicity without their uncertainties, is presented in Fig. 4. Here, the ratio of data to theory was fitted to a constant value at high- p_T , and the results plotted as a function of \sqrt{s} . The results suggest an energy dependence in the ratio of data to theory for γ/π^0 production, already noted in Figs. 1–3. There are also substantial differences between experiments at low \sqrt{s} , where the observed γ/π^0 is smallest, which makes it difficult to quantify this trend. Recognizing the presence of these differences is especially important because only the direct-photon experiments at low energy have been used in PDF fits to $G(x)$.

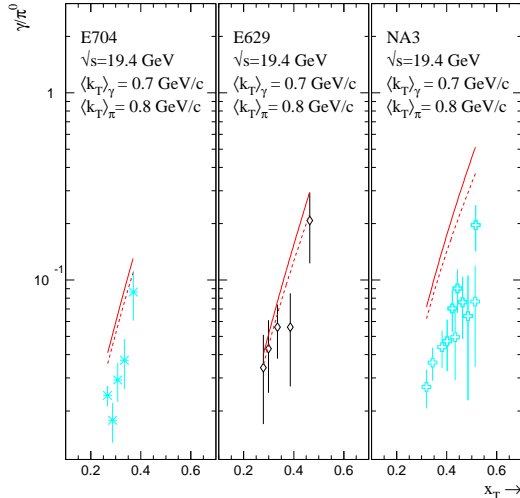


Figure 1. Comparison of γ/π^0 rates as a function of x_T for NA3, E704, and E629 at $\sqrt{s} = 19.4$ GeV. Overlaid are the results from NLO pQCD (solid) and k_T -enhanced calculations (dashed). Values of $\langle k_T \rangle$ used for the k_T -enhanced calculations are given in the legend.

2 Corrections for Soft Gluon Emission

In the absence of a rigorous theoretical treatment, a more intuitive, but often successful, phenomenological approach has been used to describe soft gluon radiation in high- p_T inclusive production,⁴ and parametrized in terms of an effective k_T that provided additional transverse impulse to the outgoing partons. This provided p_T -dependent corrections to the NLO pQCD calculations. The corrections for direct- γ and π^0 production in Fermilab experiment E706 are large (and comparable) over the full range of p_T .¹ The corrections depend on the values used for $\langle k_T \rangle$, with changes of 200 MeV/c making substantial difference, and therefore making it difficult to obtain the precision needed for extracting global parton distributions. In addition, there are different ways to implement such models,^{1,5} which can produce quantitative differences in the k_T -correction factors. However, it is expected that, in the ratio of γ and π^0 cross sections, the impact of k_T cor-

rections should be minimal, and this is observed in Figs. 1–3, where the dashed curves indicate the predicted ratios using previous k_T corrections.⁴ Thus, it seems that the trend in Fig. 4 cannot be understood purely on the basis of corrections for k_T .

Resummed pQCD calculations for single direct-photon production are currently under development.^{6,7,8,9,10,11} Two recent threshold-resummed pQCD calculations for direct photons^{6,7} exhibit far less dependence on QCD scales than NLO theory, and provide an enhancement at high p_T . A method for simultaneous treatment of recoil and threshold corrections in inclusive single- γ cross sections is also being developed.¹¹ This approach accounts explicitly for the recoil from soft radiation in the hard-scattering, and conserves both energy and transverse momentum for the resummed radiation. The possibility of substantial enhancements from higher-order perturbative and power-law nonperturbative corrections relative to NLO are indicated at both moderate and high p_T for fixed-target energies, similar to the enhancements obtained with simple k_T -smearing.⁴

Although there are discrepancies between experiments, especially significant at low \sqrt{s} , there appears to be an unexplained systematic trend with energy in Fig. 4. Hopefully, this can be clarified once resummation calculations for inclusive pion production become available. Nevertheless, the recent developments in theory of direct- γ processes provide cause for optimism that the long-standing difficulties in developing an adequate description of direct- γ production can eventually be resolved, making possible a reliable extraction of $G(x)$ from such data.

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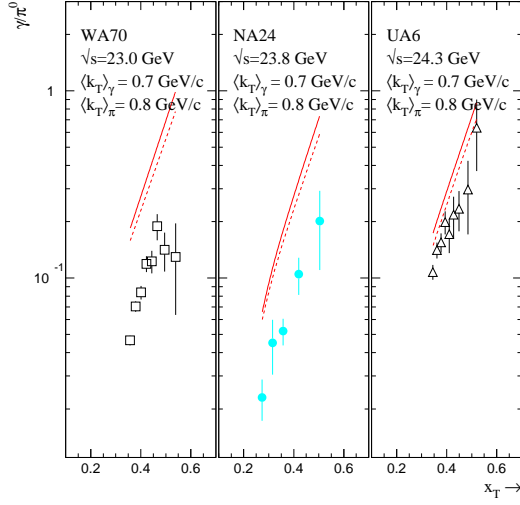


Figure 2. Comparison of γ/π^0 rates as a function of x_T for WA70, NA24, and UA6 at $\sqrt{s} \approx 23-24$ GeV. (See text and Fig. 1 for additional explanation.)

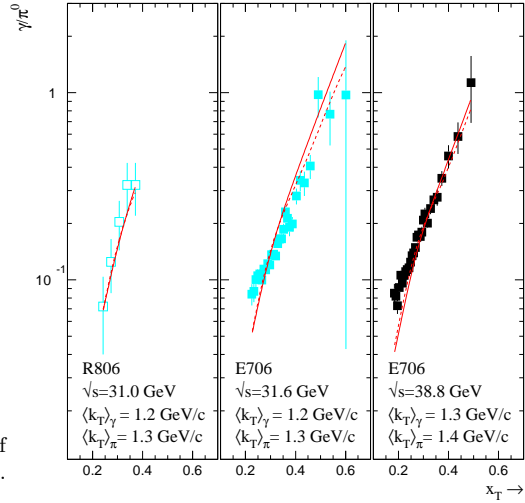


Figure 3. Comparison of γ/π^0 rates as a function of x_T for R806 at $\sqrt{s} = 31$ GeV and E706 at $\sqrt{s} = 31.6$ and 38.8 GeV. (See text and Fig. 1 for additional explanation.)

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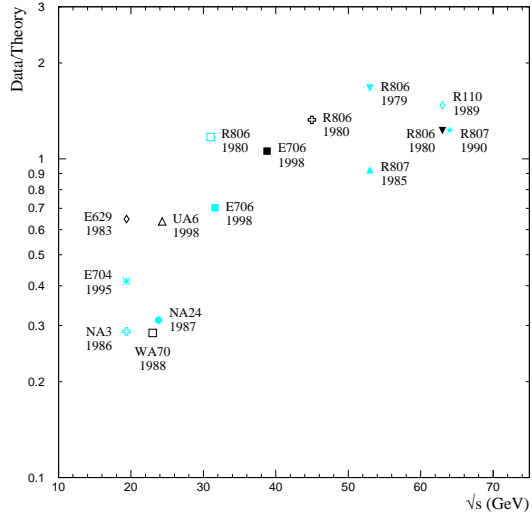


Figure 4. Ratio of data to NLO for the γ/π^0 production as a function of \sqrt{s} .¹ The values represent fits to the ratio of data to NLO pQCD theory, without k_T -enhancement (see text).